

SEÇÃO I - FÍSICA DO SOLO

INFLUENCE OF SURFACE CRUST ON WATER INFILTRATION RATES MEASURED BY A ROTATING-BOOM RAINFALL SIMULATOR AND A DOUBLE-CYLINDER DEVICE⁽¹⁾

R. LEVIEN⁽²⁾, Q. DE JONG VAN LIER⁽³⁾ & A. G. C. ALVES⁽⁴⁾

SUMMARY

Soil water infiltration rate, together with rainfall rates determine runoff rates, being an important parameter for erosion estimation and soil conservation studies. Measurement of infiltration rates can be performed using a double-cylinder device (CD) or a rotating-boom rainfall simulator (RS). The use of CD is less laborious in comparison with RS instruments, but results often do not agree with rates occurring in real rainfall situations, possibly due to surface crust formation. Crust formation depends both on factors that do not depend on soil management, such as rainfall intensity and soil texture and on factors that do depend on soil management, mainly soil strength and crop residue cover. In situations where crust formation is likely to occur, infiltration rates measured by CD will probably overestimate real infiltration rates occurring during rainfall events. To verify if there is a correlation between soil management and the ratio between infiltration rates determined using RS and CD, infiltration rates were measured by both methods on two Ultisols in southern Brazil. Plot treatments differed in crop residue cover and removal or not of preexisting crust. RS measurements were made using a rotating-boom rainfall simulator with a Veejet 80100 nozzle over 3.5 x 11.0 m plots, generating a rainfall intensity of 64.2 mm h⁻¹ during 100 to 150 minutes. Plots were bordered by steel plates and runoff was collected at the lower border for 3 seconds every 3 minutes. The CD was composed of an inner and an outer cylinder (diameter 0.30 m and 0.60 m, respectively), driven into the soil to a depth of 0.10 m, shortly before RS determinations. The area inside the cylinders was flooded and infiltration rates within the inner cylinder were registered at regular time intervals, making three replicates per plot. Results showed CD measured final infiltration rates to be five to tenfold greater than RS. CD measurements are closer to RS measurements

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⁽²⁾ Professor do Departamento de Solos, Faculdade de Agronomia, Universidade Federal do Rio Grande do Sul - UFRGS. Caixa Postal 776, CEP 90001-970 Porto Alegre (RS).

⁽³⁾ Professor do Departamento de Ciências Exatas, Escola Superior de Agricultura "Luiz de Queiroz" - ESALQ. Caixa Postal 9, CEP 13418-900 Piracicaba (SP), Brasil. Bolsista do CNPq. E-mail: qdjvlier@carpa.ciagri.usp.br

⁽⁴⁾ Professor do Departamento de Biologia, Universidade Federal Rural de Pernambuco - UFRP. Av. D. Manoel de Medeiros s/n, CEP 52171-900 Recife (PE).

when soil cover is present. Instant infiltration rates are more similar when no preexisting surface crust exists. These results show that infiltration rates determined by CD and RS cannot be used in soil conservation studies without correction and that correction factors should consider management conditions, especially those related to soil crust existence and formation, and presence of residue cover.

Index terms: Infiltration rate; double cylinder device; rainfall simulator; surface crust, surface degradation, erosion.

RESUMO: *INFLUÊNCIA DA CROSTA SUPERFICIAL NAS TAXAS DE INFILTRAÇÃO DE ÁGUA MEDIDAS COM SIMULADOR DE CHUVA E ANÉIS CONCÊNTRICOS*

A taxa de infiltração de água no solo, conjuntamente com a taxa de chuva, determina a taxa de enxurrada, constituindo medida importante para a previsão de erosão e estudos de conservação do solo. Pode-se medir a taxa de infiltração por meio de um infiltrômetro de cilindros concêntricos (CC) ou de um simulador de chuva (SC). A utilização do CC requer menos trabalho do que o SC, mas os resultados obtidos com o CC comumente estão em desacordo com as taxas de infiltração que ocorrem em situações de chuva natural, possivelmente por causa da formação de uma crosta superficial sob chuva. A formação dessa crosta procede tanto de fatores independentes do manejo do solo, como a intensidade da chuva e a textura do solo, quanto de fatores dependentes do manejo, principalmente a resistência ao cisalhamento e a cobertura vegetal. Em situações favoráveis à ocorrência de formação de crosta, espera-se que taxas de infiltração medidas com o CC superestimem as taxas reais durante uma chuva. Para verificar a correlação entre o manejo do solo e a razão das taxas de infiltração obtidas com CC e SC, essas taxas foram medidas por ambos os métodos em dois Podzólicos (Ultissolos) da região sul do Brasil. Os tratamentos diferiram com a cobertura vegetal e com a existência de crosta superficial. Medidas da taxa de infiltração com SC foram realizadas com um simulador de chuva com bicos aspersores Veejet 80100, em parcelas de 3,5 x 11,0 m, gerando chuva de intensidade de 64,2 mm h⁻¹, durante 100 a 150 minutos. As parcelas foram delimitadas com chapas de metal e a enxurrada foi coletada no lado inferior por três segundos a cada três minutos. O CC consistiu de dois cilindros (diâmetros de 0,30 e 0,60 m), cravados no solo até 0,10 m pouco antes da determinação com o SC. A área dentro dos anéis foi inundada e as taxas de infiltração foram registradas dentro do anel interior, em intervalos de tempo regulares, com três repetições por parcela. Os resultados mostraram que a taxa de infiltração final, quando medida com o CC, foi de cinco a 10 vezes superior à medida com o SC. Medidas da taxa de infiltração com o CC diferiram menos das do SC, quando uma cobertura do solo estava presente. Taxas instantâneas de infiltração diferiram menos quando a crosta preexistente foi removida anterior aos testes. Esses resultados mostram que as taxas de infiltração determinadas pelo CC e SC não podem ser utilizadas em estudos de conservação do solo sem correção e que essa correção deve considerar as condições de manejo, especialmente aquelas relacionadas com a existência e formação de crosta superficial e com a presença de cobertura vegetal.

Termos de indexação: infiltrômetro de duplos cilindros, degradação superficial, erosão.

INTRODUCTION

Soil water infiltration rate together with rainfall intensity and duration determine runoff, being an essential soil parameter in erosion and soil conservation studies. Measurement of infiltration rates is most commonly performed using a double-cylinder device because it is one of the less labor intensive methods. However, its results often do not

agree with rates occurring in real rainfall situations, because a surface crust may form (Duley, 1939; Ben-Hur et al., 1987; Moss, 1991), especially during high intensity rainstorms, common in tropical climates. Soils with low clay content do not form layers of low permeability, while high clay content confers more stability to aggregates. A clay content of 0.20 kg kg⁻¹ has been proposed as optimum for crust formation (Ben-Hur et al., 1985).

Surface crusts have much lower saturated hydraulic conductivity than normal soil surfaces (Gimenez et al., 1992; Chiang et al., 1993) and, therefore, are limiting for the overall water infiltration process. Different saturation conditions due to surface crust formation are also reported to alter infiltration rates (Mualem et al., 1993). Crust formation depends both on factors which do not depend on soil management practices, such as rainfall intensity and soil texture, and on factors that do depend on management, mainly soil strength (Sharma et al., 1991) and crop residue cover (Lindstrom et al., 1984; Unger, 1992; Busscher et al., 1996). In situations where crust formation is likely to occur, infiltration rates measured by a double-cylinder device will probably overestimate real infiltration rates occurring during rainfall events because no crust will form when infiltration rates are measured this way. In these cases, infiltration rate measurements using rainfall simulators on bordered plots appear to be more reliable (Sidiras & Roth, 1987). Such measurements, however, require a rainfall simulator and are more laborious to install and operate. Establishing a relation between double-cylinder device and rainfall simulator infiltration rates allows the shifting from one type of measurement to the other. This relationship will, obviously, depend on crust forming factors.

The objectives of the present study were to verify how crust formation is modified by soil residue covers and how crust formation influences infiltration measurements, in order to establish a relationship between infiltration rates measured by a double-cylinder device and a rainfall simulator.

MATERIALS AND METHODS

Experimental sites

Crust formation experiments were conducted on two locations in Rio Grande do Sul, Brazil, at a latitude of about 30° S. The first location was at the experimental station of the Agronomy College of the Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, on a red, medium textured dark Podzolic soil with clay contents of 0.18 kg kg⁻¹ in the 0-0.18 m layer and 0.24 kg kg⁻¹ in the 0.18-0.37 m layer. A very dense plintite layer is present at a depth of about 0.60 m. The second site was located on an experimental forestry farm at the county of Santa Maria, on a red-yellow Podzolic soil with clay contents of 0.21 kg kg⁻¹ in the 0-0.15 m layer and 0.29 kg kg⁻¹ in the 0.15-0.40 m layer. Both soils have a udic moisture regime and a slope of about 0.07 m m⁻¹ and infiltration rates were measured on two plots per soil, 3.5 m (contour) x 11.0 m (parallel to slope) each. No correction of observed data was performed to compensate for small differences in slope.

Treatment preparation included removing soil cover from the plots when present (Table 1). Plots were then prepared by conventional tillage (disk plowing followed by two disk harrowings), after which soil cover was reestablished with the material previously removed. Plots were left bare for about a month for natural crust formation to take place. In some cases, rainfall had been insufficient to form significant crust, or of such intensity that erosion-rills had formed. In these cases, crust formation was induced by operating a rotating-boom rainfall simulator (Swanson, 1965) according to procedures described by Peterson & Bubenzer (1986). The rainfall simulator with a Veejet 80100 nozzle produced rainfall at an intensity of 32.1 mm h⁻¹ (kinetic energy of 642 J m⁻² h⁻¹) until runoff was about to begin, after which plots were allowed to dry for some days. Then, plots were bordered by steel plates and surface crust was removed on one of the plots by disk harrowing, while it was left intact on the other, shortly before the infiltration tests were taken. Five tests were run at the Porto Alegre site and two at the Santa Maria site, each of them representing different soil cover conditions as indicated in table 1.

Infiltration measurements

Each infiltration measurement started with double-cylinder infiltrometer tests (Bouwer, 1986), using cylinders with a diameter of 0.30 m (inner) and 0.60 m (outer), driven 0.10 m into the soil. The area inside the cylinders was flooded and infiltration rates within the inner cylinder were registered at regular time intervals for about 150 min at the Porto Alegre site and 100 min at the Santa Maria site, maintaining the water depth within the cylinders between 25 and 75 mm. Three replicates were made per treatment. Immediately after that, infiltration

Table 1. Dates, previous crops and soil cover for the seven infiltration tests

Test	Date	Previous crop	Cover
			m ² m ⁻²
Porto Alegre			
1	Aug 28, 1989	none	0
2	Dec 12, 1989	Wheat (<i>Triticum aestivum</i>)	0.70
3	Feb 08, 1990	Maize (<i>Zea mays</i>)	0.17
4	Mar 29, 1990	none	0
5	May 25, 1990	Maize (<i>Zea mays</i>)	0.23
Santa Maria			
6	Oct 15, 1991	none	0
7	Oct 22, 1991	Maize (<i>Zea mays</i>)	0.55

rate was determined using the same rotating-boom rainfall simulator described before, now regulated to produce rainfall intensities of 64.2 mm h⁻¹ (kinetic energy of 1284 J m⁻² h⁻¹) over the plots during 150 min (Porto Alegre) or 100 min (Santa Maria). Runoff was collected at the lower border for 3 seconds every 3 min. Infiltration rates were determined as the difference between simulated rainfall intensities and runoff rates. In this paper, infiltration rates determined in the double-cylinder device are referred to as *I_c*, whereas for those determined by the rainfall simulator *I_s* is used.

In order to smooth down and interpolate infiltration rates (*I_c* and *I_s*), data were fitted to the Kostiakov (1932) equation, modified by addition of a lower threshold parameter *a*:

$$I = a + bt^c \tag{1}$$

in which *I* (mm h⁻¹) is the infiltration rate, *t* (h) is time and *a* (mm h⁻¹), *b* (mm h^{-(c+1)}) and *c* are regression parameters.

RESULTS AND DISCUSSION

Observed data fitted well to equation 1, values of *r*² being higher than 0.90 for all cases (Figure 1). Comparing infiltration rates with no initial crust for treatments with lowest (no cover) and highest residue cover (0.70 m m⁻²) on the Porto Alegre plots (Figure 1a), the final values for highest cover tend to a value of 15 mm h⁻¹, while those for lowest cover are about 30% lower. These differences may be explained by the possible formation of a surface crust on the no-cover plot. However, for the Santa Maria plot (Figure 1b), the opposite occurred. The treatment with 0.55 m² m⁻² residue cover showed lower infiltration rates than that without cover. This unexpected behavior may be attributed to the fact that initial soil conditions were different due to tillage practices, also evidenced by significantly lower cylinder infiltration rates for treatment with 0.55 m² m⁻² residue cover, as shown in table 2.

Infiltration rates after 2 h of infiltration by rainfall simulator and cylinder, with and without

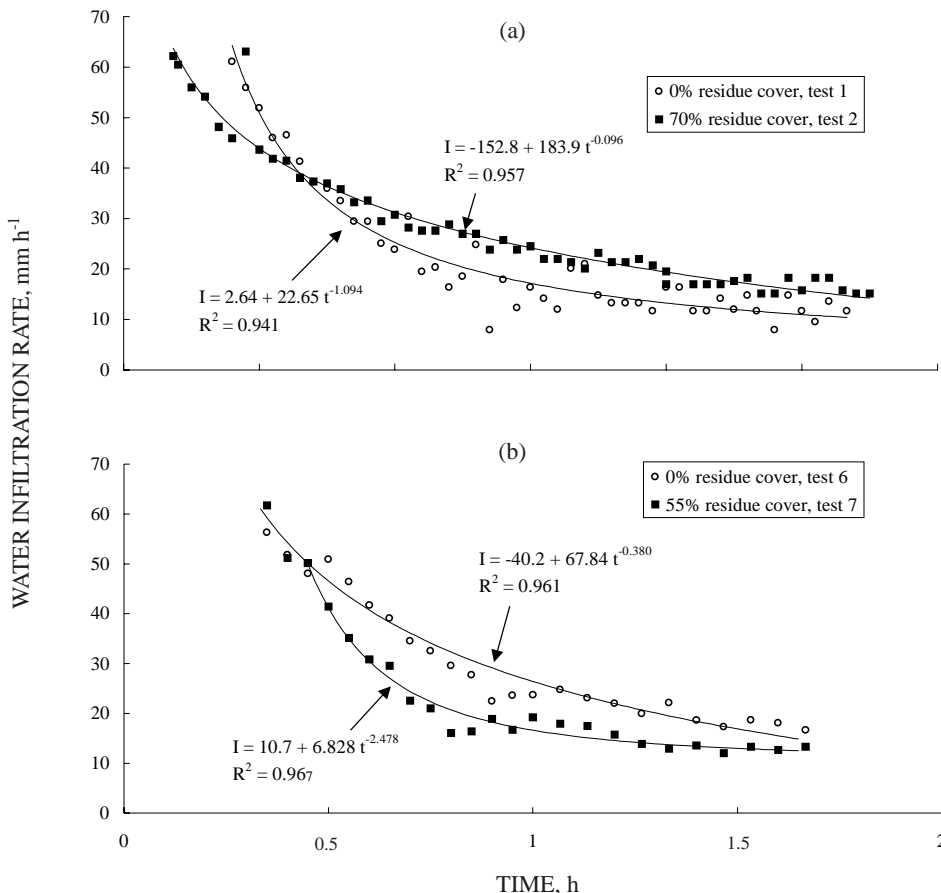


Figure 1. Water infiltration rate versus time for plots with no initial crust, under simulated rainfall (a) during tests 1 and 2 (Porto Alegre) and (b) during tests 6 and 7 (Santa Maria).

Table 2. Infiltration rates for the seven tests, after 2 hours of infiltration for rainfall simulator (*Is*) and cylinder device (*Ic*) with and without initial crust

Site ⁽¹⁾	Cover	<i>Is</i>		<i>Ic</i>	
		Initial crust	No initial crust	Initial crust	No initial crust
	m ² m ⁻²	mm h ⁻¹			
PA	0.00	22.2	19.2	296.4	128.4
PA	0.70	14.4	19.2	73.8	91.8
PA	0.17	12.6	12.0	62.4	94.2
PA	0.00	15.0	12.0	185.4	136.8
PA	0.23	15.0	13.2	82.8	195.0
PA	mean	15.8	15.1	140.2	129.2
SM	0.00	24.0	26.4	166.2	85.8
SM	0.55	28.2	16.8	56.4	25.2
SM	mean	26.1	21.6	111.3	55.5

⁽¹⁾ PA = Porto Alegre; SM = Santa Maria.

crust, are compared in table 2. No tendency could be observed between residue cover at the final rainfall simulator infiltration rates, in which the presence or not of an initial crust did not alter final infiltration, opposite to the findings of Baumhardt & Lascano (1996), who found a clear correlation between these factors for a clay-loam. In the present case, even for the highest soil residue covers, *Is*-values were similar to those obtained on bare plots, suggesting that the studied soils have a low structure stability and, even protected by a cover, crusts are formed easily. As infiltration rates were much lower than simulated rainfall intensity, this may be due to dispersion caused by runoff, or to soil particle chemical dispersion, as discussed by Agassi et al. (1985) and Kim & Miller (1996). Santa Maria mean *Is*-values are higher than Porto Alegre mean values (Table 2). Results show a five to tenfold overestimation of final infiltration rates by the double-cylinder device when compared to the rainfall simulator. This corroborates to observations made by Ben-Hur et al. (1987) and Sidiras & Roth (1987), among others, who found increases of the same magnitude.

With the exception of a few observations at the very beginning of some tests, values of *Is* were always smaller than those of *Ic* (Figures 2 and 3). These figures illustrate the *Is/Ic*-ratio over time for the Porto Alegre and Santa Maria tests, respectively. Low values of infiltration, even at the beginning of the tests on most of the plots with no initial crust, indicate that surface crust formation on these soils is a fast process. Cylinder infiltration rates did not decrease significantly between 30 and 120 min, while rainfall simulator infiltration rates decreased with time in most cases. Although no statistical comparison is possible for *Is*-values, a decreasing tendency can be observed along time, especially for

the cases in which initial crust had been removed. *Ic*-values are known to have a very high variability (Vieira et al., 1981; Sakai et al., 1992), while variability of *Is*-values is much lower, possibly because surface crust's hydraulic conductivity is less variable than that of the bulk soil (Ben-Hur et al., 1987) and because measurements apply to larger areas, smoothing small-scale variability. Figures 2 and 3 show high coefficients of variability for *Ic*, commonly in the order of 50 to 100%.

Figures 2a, 2d and 3a, representing results from tests 1, 4 and 6, respectively, are typical examples of cases where no soil cover is present. With initial crust left present, *Ic* is about 10 times higher than *Is* during the whole experiment. Although no crust is removed in these cases, the mere action of introducing the cylinder into the soil causes a crumbling of the crust, allowing about 10 times higher infiltration rates to be measured by the cylinder device. When crust is removed, the initial *Is/Ic* ratio increases considerably. Under rainfall simulator measurements, formation of a new crust rapidly reduces *Is/Ic*, corroborating with observations by Duley (1939) and approaches its final value after about 2 h. Variations in *Is/Ic* are mainly due to variations in *Is* (Figure 2a, 2d and 3a).

During the final part of some tests, notably test 2 (Figure 2b) and 3 (Figure 2c), an increase in *Is/Ic*-ratio is observed for the plots with initial crust. This increase is mainly due to a decrease in *Ic*-values, which may have been caused by soil saturation from deeper, less permeable soil layers.

Overestimation by the double-cylinder device is reduced significantly by the presence of the soil cover (Figure 2b), even for thinner soil covers (Figure 2c). In figure 2b, representing test 2 with a 0.07 m² m⁻² soil

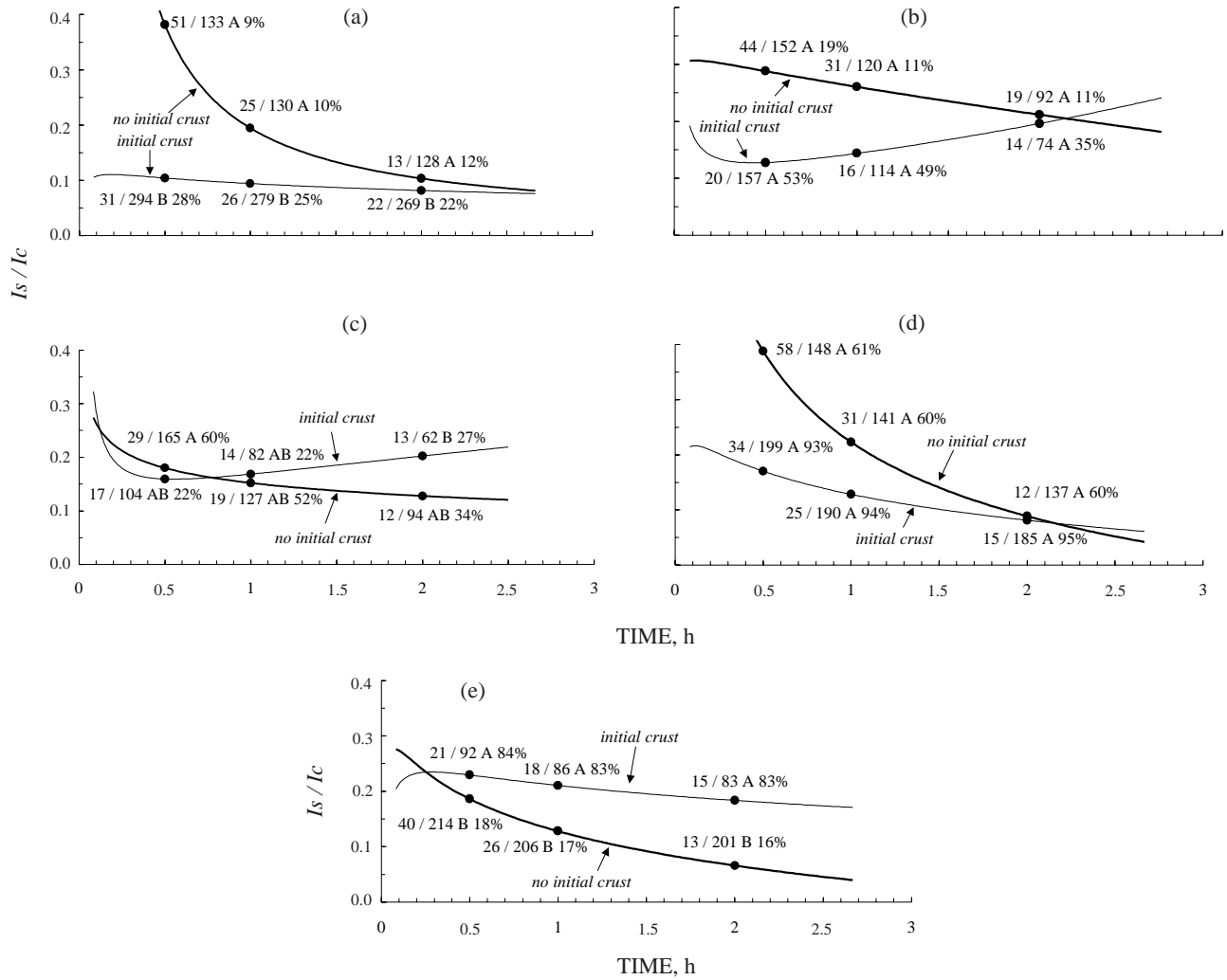


Figure 2. Ratio between water infiltration rates measured at the Porto Alegre location, using a rainfall simulator (I_s) and a cylinder device (I_c) along time (a) test 1 (b) test 2 (c) test 3 (d) test 4 (e) test 5. Observed infiltration rates (mm h^{-1}) I_s/I_c , Duncan's test ($P < 0.05$) group classification and variance coefficient after 0.5, 1 and 2 h are indicated.

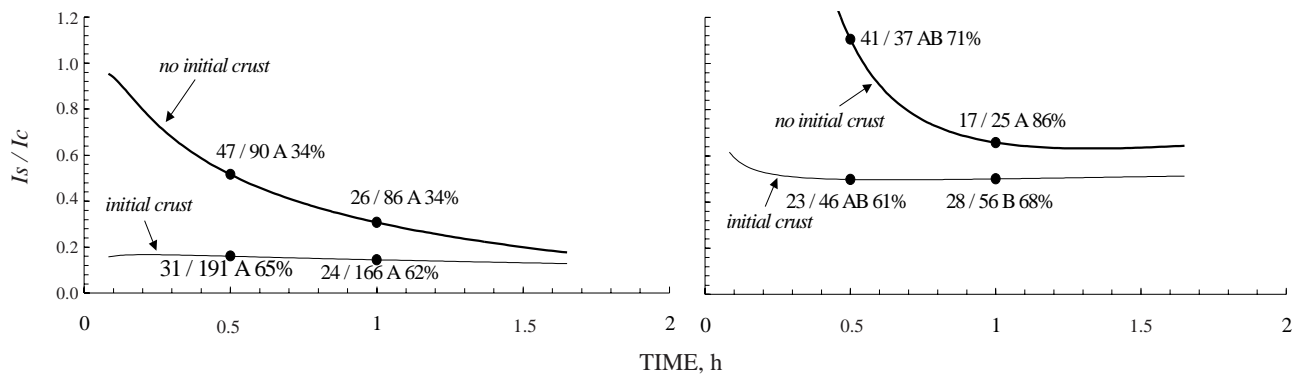


Figure 3. Ratio between water infiltration rates measured at the Santa Maria location using a rainfall simulator (I_s) and a cylinder device (I_c) along time (a) test 6 (b) test 7. Observed infiltration rates (mm h^{-1}) I_s/I_c , Duncan's test ($P < 0.05$) group classification and variance coefficient after 0.5 and 1 h are indicated.

cover, the I_s/I_c ratio came close to 0.2 after 2 h, with or without initial crust. In the same way as observed for test 1 (Figure 2a), initial I_s -values were much higher for the no-crust plot, reducing rapidly. On the crust plot, a reduction also took place, though less evident. Similar tendencies were observed for test 3 (Figure 2c). The apparent difference between final I_s/I_c ratios for crust and no-crust plots is due to the difference in I_c , which, however, is statistically insignificant.

I_s -values behave more differently through time than I_c -values, as shown in figure 4 by the ratio between I_s -values after 120 and after 30 min, as a function of soil cover. A positive linear relationship ($r^2 = 0.6581$) was obtained for the plots without initial crust.

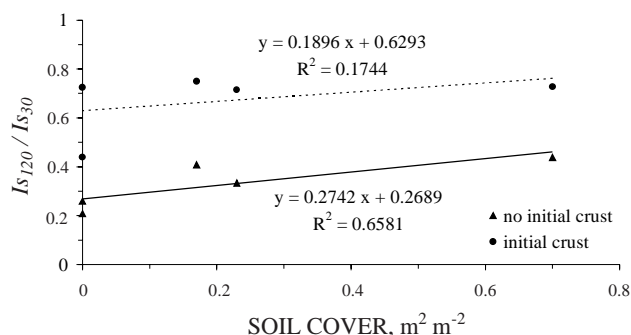


Figure 4. Ratio between I_s -values after 120 and after 30 min at the Porto Alegre location, as a function of soil cover.

CONCLUSIONS

1. Final infiltration rates measured under simulated rainfall of 64.2 mm h^{-1} are five to ten times lower than those measured with a double-cylinder device, even when a preexisting crust is present and independent of soil residue cover.

2. Surface crust formation under simulated rainfall of 64.2 mm h^{-1} occurs within little time and its effect on infiltration rate after 1 to 2 hours equals that of a preexisting naturally formed crust. The velocity of crust formation was not correlated with soil residue cover. Soil cover may, therefore, increase soil infiltration capacity for short term rainfall events.

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